Methods and Techniques in Determining Spray Quality

R.D. Fox, R.C. Derksen, H.E. Ozkan, R.D. Brazee[1]

Abstract:

The efficacy of chemicals sprayed on plants to control pests depends on chemical formulation, concentration and deposit pattern on foliage. The application pattern on the leaf is the key to optimizing efficient utilization of pesticides. The current goal of an ideal application is to apply spray uniformly throughout the plant canopy. However some pests are concentrated in specific sections of the canopy, i.e., the bottom center, the top center, or perhaps on the under side of leaves. In these cases we may want to target spray to the infested regions and a non-uniform pattern would be preferred. At a smaller scale, the deposit pattern on individual leaves or fruit may be important. Several techniques for assessing the deposit pattern are discussed. Again, the specific target pest or pesticide used may determine the best deposition pattern.

INTRODUCTION

The adoption of precision farming on a wide scale would reduce pesticide use by permitting IPM principles to be applied to pesticide spraying on a more precise scale, equivalent to the block size used in each field. Precision farming will require sprayers that can control application rate and other spray variables while spray is being applied. Spray efficiency could be improved still more if optimum coverage and drop size relationships were known and integrated into spray controller algorithms during field operations.

The efficacy of chemicals sprayed on plants to control insects and diseases depends on the chemical formulation, its concentration and its deposit pattern on targeted area (leaves, fruits, branches, etc.). With increasing pesticide costs and the development of highly active chemicals, it is essential to apply pesticides effectively. Active ingredients should be applied in the most effective droplet sizes and uniformly on the foliage with optimum distance between the droplets (Kirk et al. 1992; Alm et al. 1987; Furness, 1993; Furness et al. 1993). Sprayed areas with large between-droplet distances may not effectively control insects or diseases (Magarey et al. 1993). Chemical exposure without killing all of the insects may result in survival of pests resistant to the chemical (Alm et al. 1987).

To overcome inefficient coverage an overdose of chemical is often sprayed (Reichard et al. 1987). Using excess chemical is expensive, may pollute the environment and leave hazardous residues on edible fruits and vegetables. Better coverage of cotton plants has resulted in lower chemical use and the ability to use less toxic chemicals while controlling insect and disease (Manor et al. 1991; Zur et al. 1991;

---

[1]**Robert D. Fox, Richard C. Derksen**, Agricultural Engineer, USDA-Agricultural Research Service (ARS), Application Technology Research Unit (ATRU), Wooster, OH; **H. Erdal Ozkan**, Professor, Food, Agricultural, and Biological Engineering (FABE) Department , OSU, Columbus, OH; and **Ross D. Brazee**, Research Leader, USDA-ARS, ATRU, Wooster, OH.

Veierov et al. 1994). Kalter (1992) found that detergent applied with vertical air ducts that gave uniform adaxial and abaxial leaf coverage throughout the canopy was nearly as effective as pesticide in controlling Bemisia Tabaci on cotton. Clearly, deposit pattern was important in control using detergent.

I. Factors effecting optimum spray deposit pattern

Spray application effectiveness could be improved greatly if the desired spray pattern on the target leaves was defined precisely. Unfortunately, many factcrs affect the optimum spray deposit pattern, so the best spray deposit for one situation may not be optimum for another crop or pest. Currently the goal of all spraying operations is to produce the same deposit amount and pattern on all parts of the plant canopy. This is never achieved. Sometimes we adjust the droplet size to provide better control of specific pests, but canopy penetration, bottom of leaf coverage, targeting pests in specific parts of the canopy are not routinely addressed with current technology and spraying practices. What size droplets are optimum for each crop/pest? Several studies have found that smaller droplets are more effective when using certain pesticides for control of specific pests such as: spruce budworm, Himel (1969), spider mites, Alm et al. (1987), whitefly, Mboob (1975), and eggs, Munthali and Wyatt (1986). Other pertinent questions follow. How much can proper timing reduce the dose required for pest control? Can we pinpoint the optimum time for spray applications? Is a uniform deposit pattern the best for all pests? Ford and Salt (1987) provide a complete review of spray deposits and their transfer to insects.

Over time, I believe many of these questions will be answered, and new and more effective pest control procedures will be developed. Among these might be controlling migrating pests at the beginning point of the migration; intercepting migrating pests en route; controlling pests at the most susceptible stage of their growth cycle; making better use of pest activities to help spread pesticide to optimum target sites; etc.

Target pest characteristics that define the most effective spray application/optimum deposit pattern include: site of canopy activity; feeding habits; movement patterns; life cycle; alternate hosts; egg deposit sites and patterns; and characteristics of all growth stages. Adams et al. (1987) measured the relative influence of drop size, droplet density, pesticide concentration, formulation and time of application on control of glasshouse whitefly. Sharkey et al. (1987) present a model that defines an optimum spray deposit for sedentary pests. Hall et al. (1995) developed a model for predicting the transfer of sprayed droplets to feeding larvae. Falchieri et al. (1995) measured the effect of spray droplet density and pesticide concentration on the feeding habits and mortality of gypsy moth larvae.

The site and type of activity of the pesticide is also an important factor on defining deposit patterns and spray targeting. Some pest control agents are effective because they repel the pest. I believe that bio-control agents will include more products that use this type of action. Similarly, some spray materials are irritants, which cause the pest to change their behavior. Toxic chemicals may have several modes of action. The insect may be affected by external contact with the sprayed material or may have to ingest the spray before it becomes active. Systemic chemicals in general have less critical deposit pattern requirements than non-systemic agents. However, some systemic materials are more effective if they are applied in higher or lower concentrations, dry

slower, or are applied in larger droplets.

Measurement methods

Introduction

Spray deposits from most applications produce great variability among collectors, even the same collector with different replications. It is difficult to obtain statistically significant differences among treatments, even if a large number of replications are made. Therefore many analysis methods developed recently have the goal of improving the speed of measurement, so that greater number of samples can be collected.

Collectors

The best collector for spray deposits is probably actual leaves. However, using leaves contributes to the difficulty of image analysis. First or all leaves are not flat; they have veins, ridges and undulations. It is difficult to obtain a uniform camera focus when the image is captured. Any out of focus sections of the image makes measuring droplet size (and even identifying small spots) questionable. Leaves also are difficult to store, so must be processed quickly. Leaves are different sizes, so an additional target size measurement is required. If leaves are picked directly from the target plant, then multiple passes with collectors in the same location can not be made. For these reasons, artificial (non-plant) materials are often used as spray droplet collectors. Sample leaves should always be tested for background deposits of the tracer material. One of our experiments was ruined because previously sprayed fungicide (copper) was found in large amounts on all leaves.

Other materials used for collectors include plastic sheets, filter and other papers, metal plates, strings, cloth, glass slides, and screen. Collectors that are not plant leaves or other living plant parts are often called 'artificial' collectors or targets. Properties of the collector should be considered before they are selected. Some targets like glass slides and plastic tape may have problem with spray run-off, if they are located close to the sprayer and high volume rates are applied. The tracer material should be tested with the collector to determine how much of the dried tracer can be washed from the collector. Some materials (cotton strings) tend to adsorb some fluorescent tracers and only 50% of applied spray may wash off. Some filter material (especially fiber-glass) tends to fall apart during washing, especially if alcohol is used as a solvent. The fibers tend to attenuate the light beam in some instruments (fluorometer) which results in erratic readings.

Tracer materials

Tracers include pesticides, fluorescent materials, salts, metal compounds, and food coloring or other dyes. An actual formulated pesticide is probably the best tracer, however, workers may be exposed to the pesticide for an extended time during experiments. Analysis for pesticides usually requires a Gas Chromatography (GC) or other expensive methods. For these reasons, other tracer materials are used to simulate the pesticide.

Salt sprays, such as foliar fertilizer, have been used as tracers. They can be detected with inexpensive conductivity meters and are readily soluble in water. In general, the detection threshold is not as low as for some other tracers and there are many sources of contamination. Metal compounds (copper, manganese, iron, etc.) have been successfully used. Copper salts can be measured with an inexpensive instrument such as a colorimeter, however, sensitivity thresholds is not a low as some other tracers.

Other metals require instruments such as atomic absorption spectrometers (AAS) for detection, but are usually quite contamination free.

Fluorescent tracers are widely used, but they have several problems that must be considered before they are used. An ideal fluorescent tracer would be soluble in water, fluoresce when dry, and not degrade in sunlight. We have not been able to locate many tracers that meet these criteria. Many florescent materials degrade (their fluorescent intensity decreases) when they are exposed to ultra-violet (u-v) radiation. Experiments conducted in sunlight may result in degraded samples. We have found that degradation is greater when spray droplets are liquid. Therefore the degradation rate is likely to depend on droplet size. Many fluorescent materials are powders (about .1 to 1 μm) and some questions have be raised about how well they may be distributed in small spray droplets (1 to 10 μm in diameter). There are many fluorescent materials available, in many colors. Therefore compatible tracers can be found that can be mixed without affecting the measurement of either. Often we like to use two sprayer treatments in the same weather conditions, and being able to separate tracers applied to the same collectors is very convenient.

Other factors

The formulation of the spray mixture must be considered. Most active chemicals contain adjuvants such as solvents, surfactants and other materials to stabilize the product and for easy mixing in water. Either blank pesticide (the same formulation without the active ingredient) or some common surfactant should be added to the tracer to simulate actual pesticide formulations. We have found that even mixtures of dry fluorescent tracers in water may produce sprays with different $D_{V0.5}$. Adding surfactants to the spray mixture will also change the amount of droplet spreading on leaf surfaces (or any other collector surface). This is a factor in image analysis of dried spray droplets.

Another consideration for spray trials is the quality of the source water used for the tank mixture. In the U.S.A. the quality of the water may change from one section of the country to another. Some water contains many mineral ions that may affect the solubility of tracers. In some cases, a celating agent is added to improve solubility. The pH of the water may also affect the mixing of tracers or other chemicals.

The sensitivity (useful threshold of detection) of instruments is important in determining whether a tracer system can be used for a particular experiment. When measuring deposits near a sprayer, such as deposits on a canopy or the ground, measuring small tracer amounts is not as important as when measuring deposits several hundred meters downwind in a drift experiment or on very small collectors (simulating a bud). A list of the instruments mentioned above, in order from least sensitive to most sensitive are: conductivity meter, colorimeter, AAS, GC, and fluorometer. GCs and fluorometers can detect deposits as low as a few parts per billion.

Wash and analyze

A standard method of measuring deposit is to wash spray collectors and analyze the wash solution for a tracer. The result of these measurements is spray deposit per unit area, which can easily be converted to percentage of applied spray. A disadvantage of this method is that many different deposit patterns may produce the same dosage, e.g., one large droplet could give the same result as 1000s of small droplets. This is still a good technique to use in addition to deposit pattern measurements, to evaluate the total deposit and to account for the total amount of spray applied.

Porskamp et al. (1993) collected spray from orchard sprayers on samples of filter paper mounted on a vertical tower. The filter paper samples were gathered quickly and weighed to determine the amount of spray deposits.

Fox et al. (1998) reported on a spray deposit analyzer developed by D. Reichard. In this system, a plastic tape (usually in a metal holder) is exposed to spray containing a small amount of a salt. The tape is pulled through the analyzer, washed with distilled water, and conductivity of the wash water measured.

Salyani and Serdynski (1990) developed an electronic sensor to measure impacting droplets. The instrument consisted of an array of parallel conductors with a voltage potential that increased as the number, size, and conductivity of spray droplets impacting on the sensor increased.

Manual visual measurement

Another traditional way of measuring deposit is by manual observation. Manual techniques may range from rating spray coverage patterns against a set of standard patterns to counting number of droplets in a sample area and measuring droplet size with a microscope. Making measurements with a microscope is tedious, time-consuming work, so the number of samples is usually limited. But the results can be quite accurate, because the human observer can evaluate spray pattern problems such as droplet overlap, variable background intensity, irregularly shaped spots, and differences in spot density that may be a problem for video-based imaging systems.

Scientists at LPCAT used a boom spray with colored dye to spray a uniform snow field. Areas receiving different application rates were clearly visible and photographs clearly showed the deposit pattern. However, collecting samples and analyzing for the dye was not successful.

Computer aided measurement

A wide range of computer based image analysis systems are now available. Most of these systems have associated software programs that implement easy computation of spot characteristics. Spot characteristics include droplets/cm^2, area coverage, and drop size distribution. These software routines may include calculation of equivalent spherical diameter, width and breadth of the spots, estimated spot overlap, and on and on. Many editing and image enhancing routines are built into the software. The software also includes macro capability wherein a series of analysis steps can be combined into one command. Thus, image analysis of a large number of targets can be carried out quickly and consistently.

Panneton and Drummond (1991) developed an imaging system with automatic focus, correction for background variation, and identification of overlapping spots. They showed that lamp intensity, as controlled by supply voltage was critical to accurate spot size measurement. Derksen and Jiang (1995) developed an automated vision system to characterize deposit. This system used computer controlled positioning with automatic focusing and image enhancement and feature extraction. They measured percent area covered, spot size, and spot roundness while using fluorescent tracers.

Franz (1993) used a hand-held scanner to quickly scan water sensitive paper and kromecoat targets for spray coverage. He developed a computer program to calculate droplet characteristics. Sample deposit measured with this system was consistent for a limited range of droplet sizes. In later studies, results from this system agreed with deposits measured with washed micro-tubing.

LPCAT has sprayed a black dye, nigrosine, in water on clear plastic tape. The tape is illuminated from below and the spray pattern image captured. Many images can be captured along the length of the tape. With a good image analysis program and a macro, a large sample of spots can be obtained quickly.

A epi-fluorescent microscope can be used to investigate spray deposit patterns. This instrument used low power lens, a strong UV light source, and interchangeable filter sets to capture images of fluorescent tracer in dried spray droplets. Standard image software is used to measure the droplet size and coverage of the captured frames. The image captured in each frame is about 5 to 10 mm in each dimension, therefore, many images must be measured to obtain a large droplet sample size. However improved resolution allows for the capture of smaller droplets than systems without microscopes. In addition, when leaf surfaces are used, it is easier to maintain a uniform focus over a smaller image area. Krause et al. (1993) used an Scanning Electron Microscope combined with X-ray dispersion to measure spray coverage using metal tracers. Coverage of 0.5 by 0.6 mm areas could be measured and the system could also confirm that the deposit contained trace element. Total area measured is necessarily limited by the size of each sample.

Problems with image analysis

Image analysis has several inherent problems that must be resolved before spray droplet pattern analysis can proceed. The video camera/imaging board system will always produce a band of gray between the spots and the background. Therefore, the size of the spots will change depending on the gray-level selected as the dividing line between white and black when the image is transformed to binary form. Some software systems use the gradient of gray scale with distance from the spot to automatically select the edge of the spot. Edge enhancing routines of many types are also available. Another problem is that the collector background may not be uniform throughout the entire image area. This is often true if leaves are used to collect droplets. Poor lighting may also cause background variability. Some software is capable of measuring the difference between spot density (gray-level) and background density at all points in the image and to correct the image so that the spot/background differences is equal throughout the image. Large spray application rates may produce too many spots. If the coverage is too great, many droplets will overlap, and it will not be possible to measure spot size accurately. The percent coverage can still be measured even if spots overlap. Some software routines are available for correcting for spot overlap, but they must be used with care. Another choice that must be

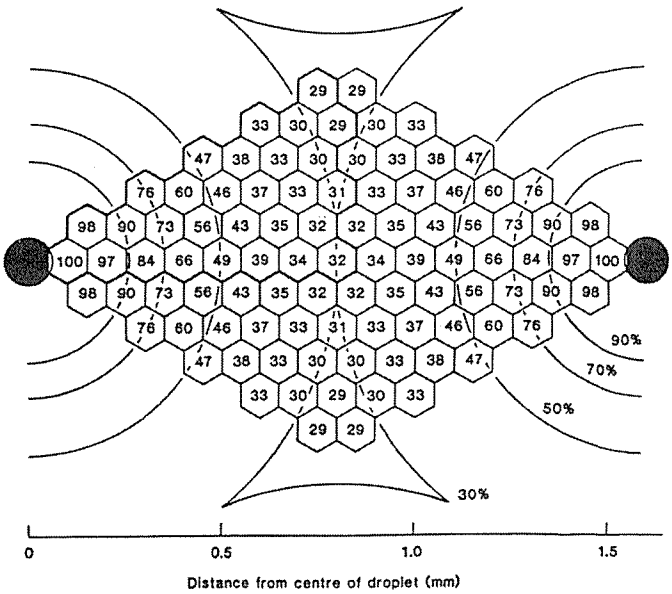

Figure 1. Estimated percent mortality of whitefly larvae between 118 μm droplets spaced 1.6 cm. From Adams et al. (1987)

made when selecting an imaging procedure is the smallest droplet size to be measured. In most cases, as the spots become smaller, they will gradually disappear, i.e., the amount of tracer material in the droplet is so small that the spots can not be distinguished from the background. Smaller spots can be measured if a greater resolution is chosen. Image area per frame is reduced to increase resolution. Then the number of images analyzed must be increased to measure the same number of spots (at least the same percent area coverage, because the smallest spots will not contribute much to the area coverage). Displaying small spots on a binary image usually requires that the gray-level cut-off be set closer to background. This may display some background points as spots, which will cause errors in the spot count. Measuring small spots (spots less than 3 pixels in each dimension) will always have a risk of including spots that are not real spray droplets.

It is important to remember the first rule of image analysis is always capture good quality images. No matter how clever the image enhancement routine, it can never produce good data from poor quality images. Time spent on improving the quality of captured images is much more productive than time spent trying to repair poor quality images.

Other measures of spray patterns

Other methods of quantifying spray deposit patterns have been proposed. Adams et al.(1987) applied uniform-sized droplets in a triangular pattern to measure the effect of drop size, pesticide concentration, and distance from the drop on the mortality of 1st instar whiteflies. From their measurements, they constructed a theoretical table of the effect of distance from uniformly spaced droplets on larvae mortality (Fig. 1). Because of the time required to conduct such studies and to construct such tables, this research approach has not been continued or expanded.

Washington (1997) measured coverage pattern differences for droplets of different size used for controlling fungi on banana leaves. He described 'the zone of inhibition' surrounding a fungicide droplet deposit on the leaf surface. Others have attempted to define this zone of activity around spray deposits.

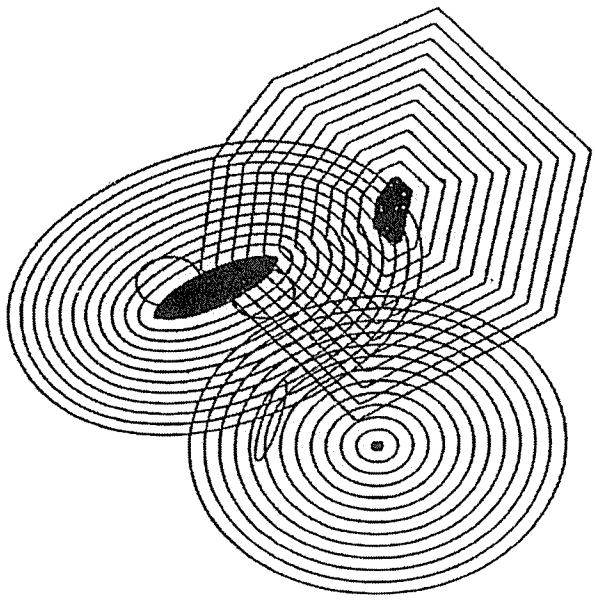

Figure 2. ERD from different shaped droplets.

Manor et al. (1994) defined an Effective Radial Distance (ERD), which is defined as the region surrounding a droplet or spray deposit on which the active ingredient has the desired affect (control) on the target insect. ERD defines a region about each deposit that can be easily calculated with imaging software and which is not greatly affected by deposit shape or size, only by the space between deposits (Fig. 2). An accurate measure of spray deposit on test media could account for variability between treatment efficacy. They computed ERD from spots on an

image by adding one row of pixels around all of the spots in the image. This added one pixel to the value of ERD. After each row of pixels was added, the percent area coverage was calculated. In this was, a plot of ERD vs percent area coverage was developed. A commercial imaging system that does this calculation is available from BarGold Electronics Ltd. By comparing ERD plots for several spray deposit patterns with efficacy studies for different pests and pesticide combinations, criteria for the optimum ERD could be developed. Again this system would require a large experimental program to develop optimum criteria for a range of pests, pesticides, drop sizes, concentrations, etc.

Adams et al. (1988) used a video system to track the movement of aphids that were exposed to a range of pesticide droplet sizes and concentrations. They measured distance walked, number of contacts with spray droplets, and time spent in the region treated with spray droplets. They found that contacts with droplets increased with distance walked, however, no factor correlated with subsequent larvae mortality. Other video systems track the movement of several insects/larvae placed in an enclosure that contains samples of pesticides or attractants. This system measures the effect of the chemical on the movement of target pests.

Spray deposit patterns are likely to be more important when bio-control agents are used. These agents will likely be less toxic and slower acting than chemical pesticides, therefore placement and distribution of bio-control agents will be even more critical than chemical agents.

DISCUSSION AND SUMMARY

Spray deposit patterns are important in the control of crop pests. This is especially true if we attempt to reduce the amount of applied pesticide to a minimum. Effective use of small amounts of pesticide will require accurate placement within the canopy with the habitat of specific pest targeted for maximum spray delivery. Then spray deposit patterns on specific canopy sections containing the pest will be critical to further reduction in the amount of pesticide required for control. Use of biological control materials will probably require even more accuracy in the deposit of the pest control agent.

The application of imaging analysis to spray deposit analysis promises to enhance the capability of scientist to measure and define spray patterns. This is the first step in identifying spray patterns that are the most effective. It is likely that the optimum spray pattern will be different for different pests, pesticides and crops. However, we can hope that similar spray patterns will be best for a range of pests with similar feeding and habitat characteristics, and for pesticide with similar modes of action. We will also have to design sprayers that can be easily configured to spray different crops and pests. Crops with different canopy shapes, limb strength and resilience, etc. will require modifications in air jets, and spray release points for maximum spray deposit efficiency.

REFERENCES

Adams, A.J., M.R. Abdalla, I.J. Wyatt and A. Palmer. 1987. The relative influence of the factors which determine the spray droplet density required to control the glasshouse whitefly, *Traileurodes vaporariorum. Aspects of Applied Biology, Studies of pesticide transfer and performance.* 14:257-266.

Adams, A.J., F.R. Hall, I.A. Rolph, and I.H.H. Adams. 1988. Video-recording aphid responses to discrete deposits of bifenthrin on chrysanthemums. *Proc. Brighton Crop Protection Conference/Pests and Diseases*. pp. 169-174.

Alm, S.R., D.L. Reichard, and F.R. Hall. 1987. Effects of spray drop size and distribution of drops containing bifenthrin on *Tetranychus urticae*. *J. Econ. Entom.* 80:517-520.

Derksen, R.C. and C. Jiang. 1995. Automated detection of fluorescent spray deposits with a computer vision system. *Transactions of the ASAE* 38(6):1647-1653.

Falchieri, D. K. Mierzejewski and S. Maczuga. 1995. Effects of droplet density and concentration on the efficacy of *Bacillus thuringiensis* and Carbaryl against gypsy moth larvae (*Lymantria dispar l.). Journal of Environmental Science and Health* B30(4):535-548.

Ford, M.G. and D.W. Salt. 1987. Behaviour of insecticide deposits and their transfer from plant to insect surfaces. In *Critical Reports of Applied Chemistry*, ed. H. Cottrell, John Wiley & Sons. London. pp 26-81.

Fox, R.D., R.C. Derksen, R.D. Brazee, H.E. Ozkan, and R.A. Downer. 1998. The Reichard spray deposit analyzer, a tool for measuring spray deposit using conductivity. AgEng '98, Oslo, Norway, Paper No. 98-A-008; Part 2, 569-570.

Furness, G.O., P.A. Magarey, R.W. Emmett and T.J. Wicks. 1993. Effective spray coverage - a vital link. *The Australian Grapegrower and Winemaker*. Sept. 1993. pp. 53-54.

Furness, G. 1993. Spraying for pests and diseases: An overview of equipment and technics. *Vine Industry Journal* 8(3):250-257.

Hall, F.R., A.C. Chapple, R.A.J. Taylor, and R.A. Downer. 1995. Modeling the dose acquisition process of *Bacillus thuringiensis,* Influence of feeding pattern on survival. ACS Symposium Series No. 595, *Biorational Pest Control Agents: Formulation and Delivery*. ed. F.R. Hall and J.W. Barry. American Chemical Society. 68-78.

Himel, C.M. 1969. The optimum size for insecticide spray droplets. *J. Economic Entomology* 62:919-925.

Jiang, C. and R.C. Derksen. 1995. Morphological image processing for spray deposit analysis. *Transactions of the ASAE* 38(5):1581-1591.

Kalter, E. 1992. Results of Bemisia Tabaci control with vertical air ducts sprayer and non-toxic chemicals. Report to the Cotton Board of Israel (Hebrew).

Kirk, I.W., L.F. Bouse, J.B. Carlton, E. Franz, R.A. Sterner. 1992. Aerial spray

deposition in cotton. *Trans. of the ASAE* 35(5):1393-1399.

Krause, C.R., R.D. Brazee, R.D. Fox, D.L. Reichard, and C.A. Tappan. 1993 Electron beam analysis of copper hydroxide spray drift applied to dormant Malus spp. *Phytopathology. 83*(12) 1351.

Magarey, R.D., M.F. Wachtel and P.A. Magarey. 1993. Downy mildew: a post-mortem lesson. *The Australian Grapegrower and Winemaker* No. 357(Sept.): 17-19.

Manor, G.R., R. Hedvati, E. Kalter, A. Geva. 1991. Aerodynamic spraying of cotton plants for better coverage and lower drift. ASAE Paper No. 911032.

Manor, G., L.R. Jarvis, J.M. Fielke. 1994. Effective spray coverage measuring procedures. Proc. World Cotton Research Conference, Australia.

Manor, G.R. and V. Shapiro. 1997. A mobile system for measuring spray coverage - BG1. 3rd International Symposium on Sensors in Horticulture, Tiberias, Israel, August 17-21.

Mboob, S.S. 1975. Preliminary assessment of the effectiveness of two droplet sizes of insecticide for the control of glasshouse whitefly, *Trialeurodes vaporariorum* (Westwood). Plant Pathology 24:158-162.

Munthali, D.C. and I.J. Wyatt. 1986. Factors affecting the biological efficiency of small droplets against *Tetranychus urticae* eggs. *Pesticide Science* 17:155-164.

Panneton, B. and A.M. Drummond. 1991. Digital image analysis of spray samples. Applied Engineering in Agriculture 7(2):273-278.

Porskamp, H.A.J., J.F.M. Huijsmans and R.P. Van Zuydam. 1993. Measuring system for the spray output distribution of orchard sprayers. A.N.P.P.-B.C.P.C. – Second International Symposium on Pesticides Application Techniques. Vol. 1, 365-371.

Reichard, D.L., R.D. Brazee, M.J. Bukovac and R.D. Fox. 1986. A system for photographically studying droplet impaction on leaf surfaces. *Trans. of the ASAE* 29(3):707-713.

Salyani, M. and J. Serdynski. 1990. Development of a sensor for spray deposition assessment. *Trans. of the ASAE* 33(5): 1464-1468.

Sharkey, A.J., D.W. Salt and M.G. Ford. 1987. Use of simulation to define an optimum deposit for control of a sedentary pest. *Studies of Pesticide Transfer and Performance, Aspects of Applied Biology* 14:267-280.

Veierov, D., N. Aharonson, E. Kalter, M. Eliahu, A. Feningstein, and S. Cohen. 1994. Non-toxic oil based formulations for the control of the sweet potato whitefly (Bemisia

Tabaci). *World cotton research conference* 1. Abstracts No. 263.

Williams, J.R. 1997. Relationship between the spray droplet density of two protectant fungicides and the germination of *Mycospaerella fijiensis* ascospores on banana leaf surfaces. *Pesticide Science* 50:233-239.

Zur, A., R. Hedvati, D. Nevo, E. Kalter, R. Levi, H. Oren, G. Manor, A. Geva. 1991. Vertical sprayer with pulsating air nozzles. *Mikun ve-Handassa Behaklaut*. April 1991. pp. 7-9 (Hebrew).